SOME UNUSUAL ASPECTS CONCERNING THE DEVELOPMENT AND STRUCTURE OF TYPHOON BILLIE—JULY 1967

ROBERT W. FETT

54th Weather Reconnaissance Squadron, Guam, Mariana Islands

ABSTRACT

Typhoon Billie exhibited mesoscale warm-core characteristics and developed winds of typhoon intensity without ever forming a wall cloud around the eye. Clouds that swirled into the storm center were flattened cumulus and stratocumulus with cloud tops at 4,000 to 5,000 ft. It was clear of all higher cloudiness in the area of the eye. The storm center lay on the northern edge of major overcast cloudiness and its appearance was similar to that of an intense Stage C tropical cyclone. Satellite pictures together with conventional analyses and information gathered by the author as a pilot on reconnaissance missions into the storm indicate that Billie intensified to typhoon strength as a result of mesoscale changes in the area of the eye. It is suggested that Billie represents a type of typhoon whose maximum wind speeds are limited because of failure to develop an encircling wall cloud.

1. INTRODUCTION

The depiction of various stages of tropical cyclone formation first devised by the author [1] in 1964 has been applied by members of the Environmental Science Services Administration (ESSA) and the Military Services over the past 4 yr. The intent of this depiction was to provide a useful "first guess" concerning the stage of development and maximum surface wind speeds to be anticipated in tropical systems observed by satellite. The model depiction is shown in figure 1. Essential to this model are Stages B and C designated the "Comma Configuration." In this configuration the center of circulation is defined by low cloud lines that are unobscured by adjacent heavier overcast cloudiness generally to the east and south. Figure 2 shows an example of a weakly defined Stage B tropical depression in the Gulf of Mexico. A definite tendency was shown for storms of progressively increasing intensity to have their centers of circulation more and more symmetric to the major overcast cloud area [2]. For example, the mature typhoon frequently assumed a "bullseye" type pattern with spiral bands wrapped almost symmetrically around the eye (fig. 3). In one of the original reports describing methods of determining maximum wind speeds in tropical cyclones from satellite pictures those storms whose centers were embedded within the overcast cloud area by less than ½° were judged indeterminate and by implication formative or less intense in nature [3].

Generally speaking, both methods for determining tropical cyclone intensity from satellite pictures have done quite well in withstanding the test of time. There are two notable areas, however, where the formative model at least has proven deficient: 1) Closed circulations have been found completely surrounded by overcast shields of middle and upper cloudiness and yet the wind speeds in the circulation have proven to be quite light. In these instances no closed center could be determined from the satellite photographs; 2) Certain storms have been found with wind speeds of tropical storm intensity or greater and yet the centers were not obscured by an overcast cloud shield or embedded to any significant degree within it. This paper is concerned with some examples of the latter variety and in particular describes some results obtained by the author on flights as a reconnaissance pilot into the eye of typhoon Billie, July 1967.

2. SOME PRELIMINARY EXAMPLES

On Aug. 15, 1964, tropical cyclone Kathy was photographed by TIROS VII weather satellite (fig. 4). The center of circulation of the storm is readily apparent in the satellite photographs as an ellipitically shaped "eye" near 29°N., 137.5°E. Because the center is not obscured by an overcast cloud shield but rather asymmetric to major overcast cloudiness to the south the storm is designated a Stage C tropical depression (see fig. 1). Wind speeds, judging from the satellite evidence, should not have exceeded 30 kt. Weather reconnaissance aircraft in the storm area, however, reported maximum surface winds of 55 kt. The eye was described by reconnaissance as elliptically shaped, east through west, having no wall cloud. Major convective activity, vertical development, and associated rainshowers were reported confined to the southern semicircle. With the exception of the reported maximum wind speeds, all other evidence is in excellent agreement with the implications of the satellite photograph. In perspective, Kathy earlier had wind speeds of typhoon intensity and also had a definite wall cloud. Later observations also indicated that wind speeds of typhoon intensity existed. There is no reason, therefore, to question the reported wind speeds obtained by reconnaissance at the time of the pictures.

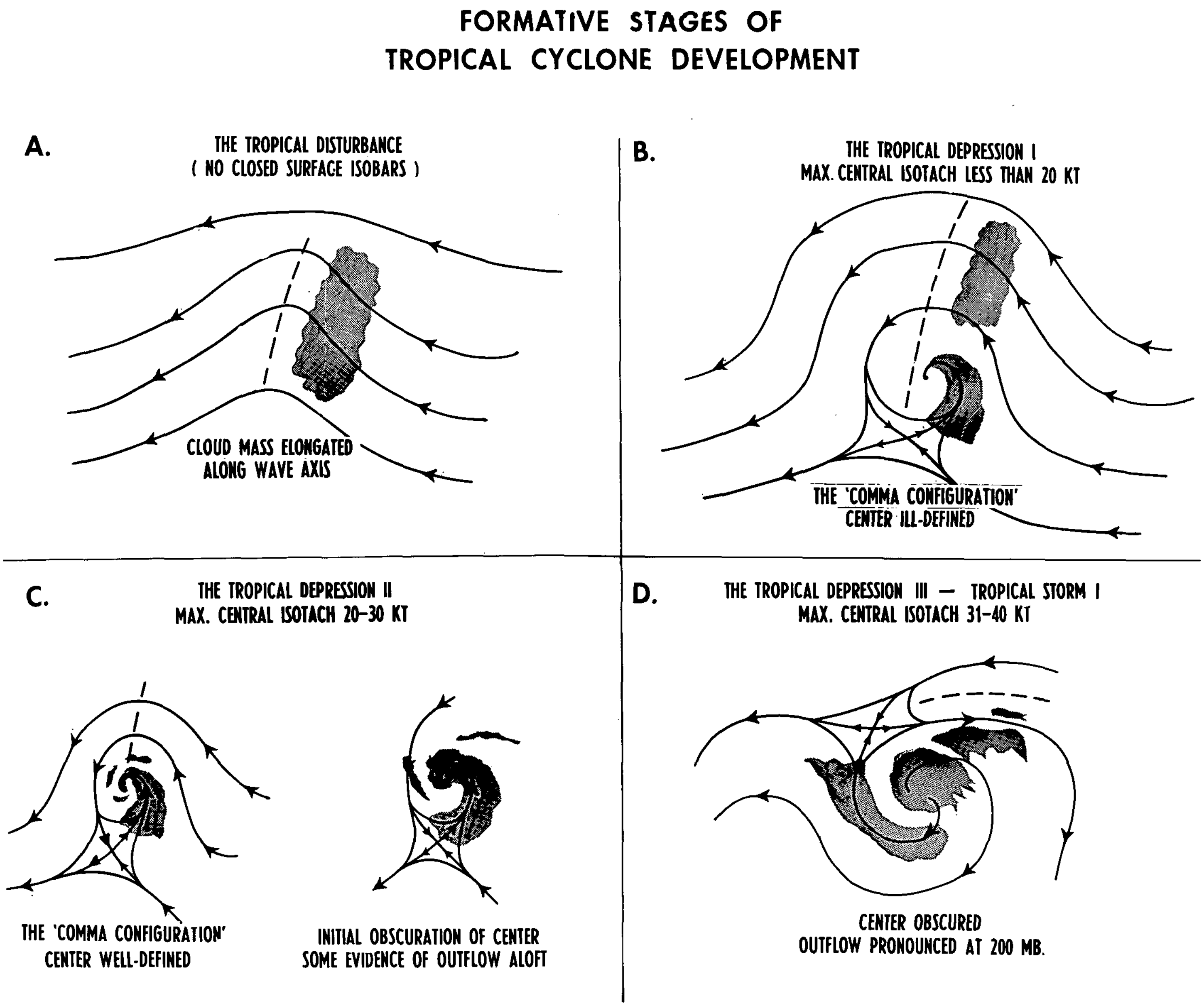

FIGURE 1.—A model describing the cloudiness distribution associated with the formative stages of tropical cyclone development. The model applies to formative tropical cyclones of the Northern Hemisphere embedded in easterly flow. In Stages A, B, and C, the typical gradient wind streamline pattern is superimposed over the shaded TIROS-observed cloudy areas. In Stage D, the typical 200-mb. streamline pattern is shown. The cloudy pattern depicting the "initial obscuration of center" is designated C+. (See [1].)

In another example (fig. 5), hurricane Ethel is shown as photographed by TIROS VII in September 1964. The center of circulation is defined by curved cloud lines on the northwest side of the storm, indicating a center near 27.8°N., 60.3°W. This position is on the very edge of major overcast cloudiness. The storm, according to the model shown in figure 1, would be categorized a Stage C tropical depression with "initial obscuration of center" indicating a more intense or highly developed state. Maximum wind speeds, however, should still have been limited to approximately 30 kt. Instead, reconnaissance reports considered highly reliable indicate that surface winds of up to 80 kt. existed just north of the storm's center. A partial wall cloud was reported in the south and east quadrants. However, the northern quadrants were open as suggested by the satellite photograph of the storm. Note that cloudiness immediately north and west of the eye position appears to be a much lower level than cloudiness to the south. The shadow of cloudiness to the southeast is superimposed on cloudiness to the northwest in an annular pattern in the western and northwestern quadrants of the storm. The shadow is clearly visible in a zone approximately 20 mi. in width. The sun's angle in this early morning picture was exactly right to produce such an effect.

It should be emphasized that these two examples of Stage C tropical cyclones with wind speeds of such high values are extraordinary departures from the overwhelm-

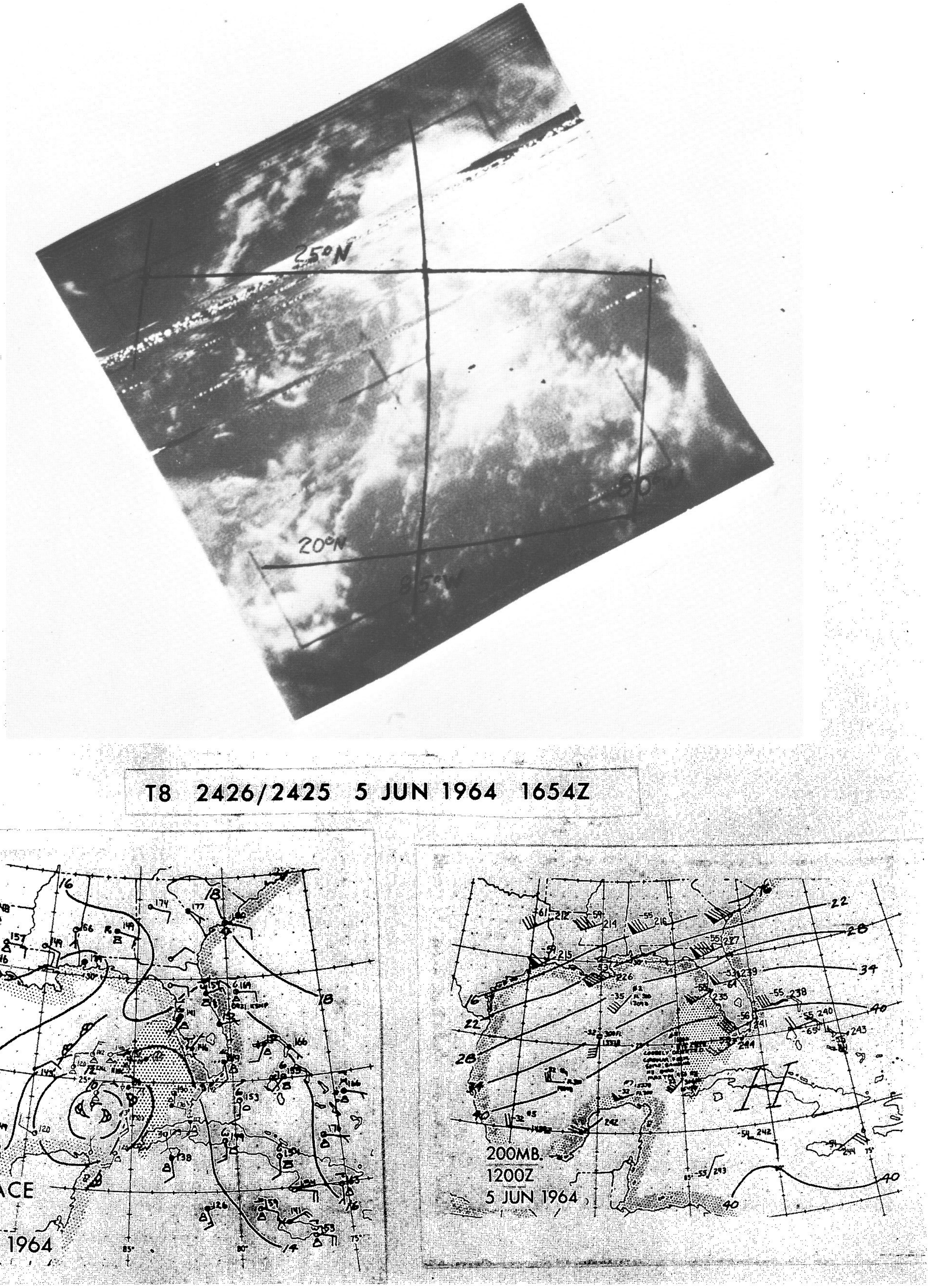

FIGURE 2.—A TIROS VIII picture of a tropical depression in the Gulf of Mexico. The surface and 200-mb. analyses with the TIROS-observed cloudy areas superimposed are also shown. The center of circulation is weakly defined by cloud lines suggesting a position near 23.5°N. and 87°W. The depression is categorized Stage B.

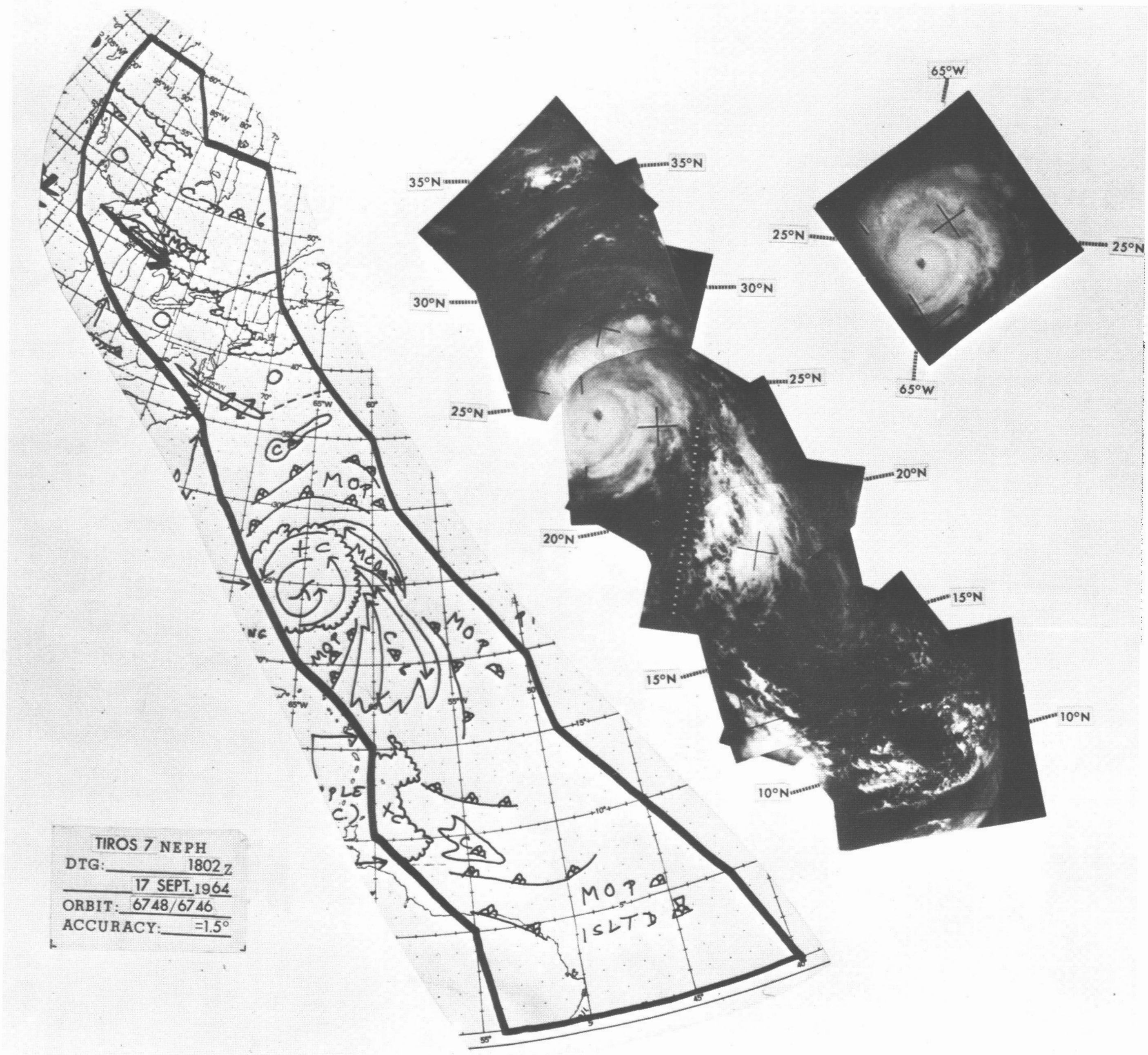

FIGURE 3.—A TIROS VII mosaic and nephanalysis showing hurricane Gladys. The elliptical eye is very apparent near the center of overcast cloudiness. Maximum surface winds were reported to be approximately 125 kt. with minimum sea level pressure of 945 mb.

ing number of cases that appear to fit the original model surprisingly well. Perhaps the degree of curvature in the low cloud banding is more pronounced and highly accentuated in these examples than in the other cases but even this point is debatable. In fact the tendency over the past few years has been to regard these storms as oddities—unusual deviations from the normal patterns. To the knowledge of the author no one to this date has documented storms of this type or has been able to explain how these storms having no wall clouds could still generate winds approaching and at times exceeding typhoon force. In July 1967 the author flew as pilot on several reconnaissance missions into the formative and later mature stages of typhoon Billie. Billie proved to be an excellent example of the type of storm previously described. Some surprising information obtained as a result of these flights now permits conclusions that may be of importance in more completely understanding the nature of these unusual storms.

3. PICTURES AND ANALYSES OF TYPHOON BILLIE

The author first flew into the area of tropical cyclone Billie on July 3, 1967. Figure 6 shows a Nimbus II picture

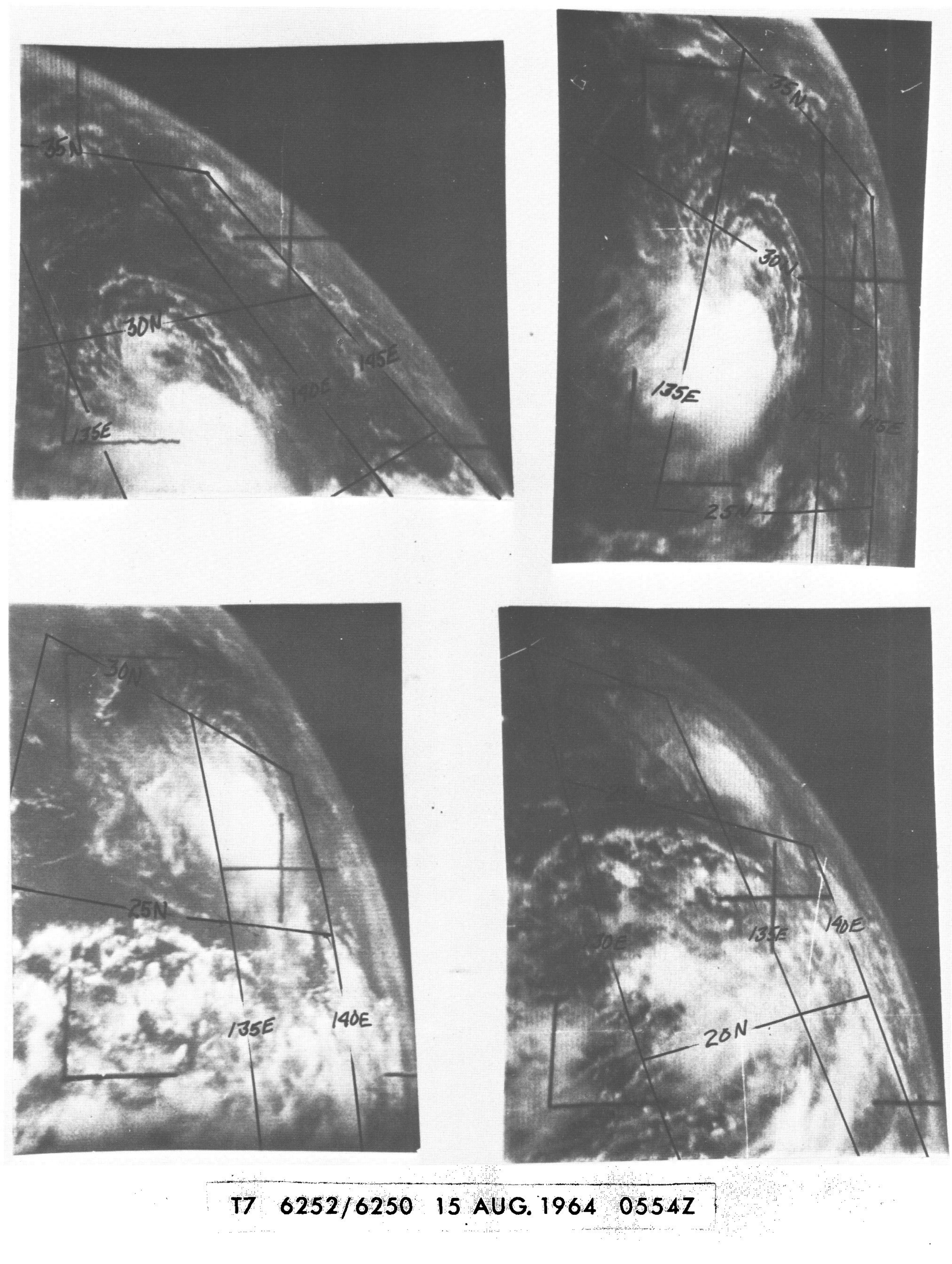

FIGURE 4.—Four TIROS VII views of tropical cyclone Kathy. Maximum winds of approximately 55 kt. were reported by reconnaissance aircraft in the area of the eye at the time of the pictures. An elliptical eye has been formed by low cloudiness north of the major area of convection. The depression is classified Stage C.

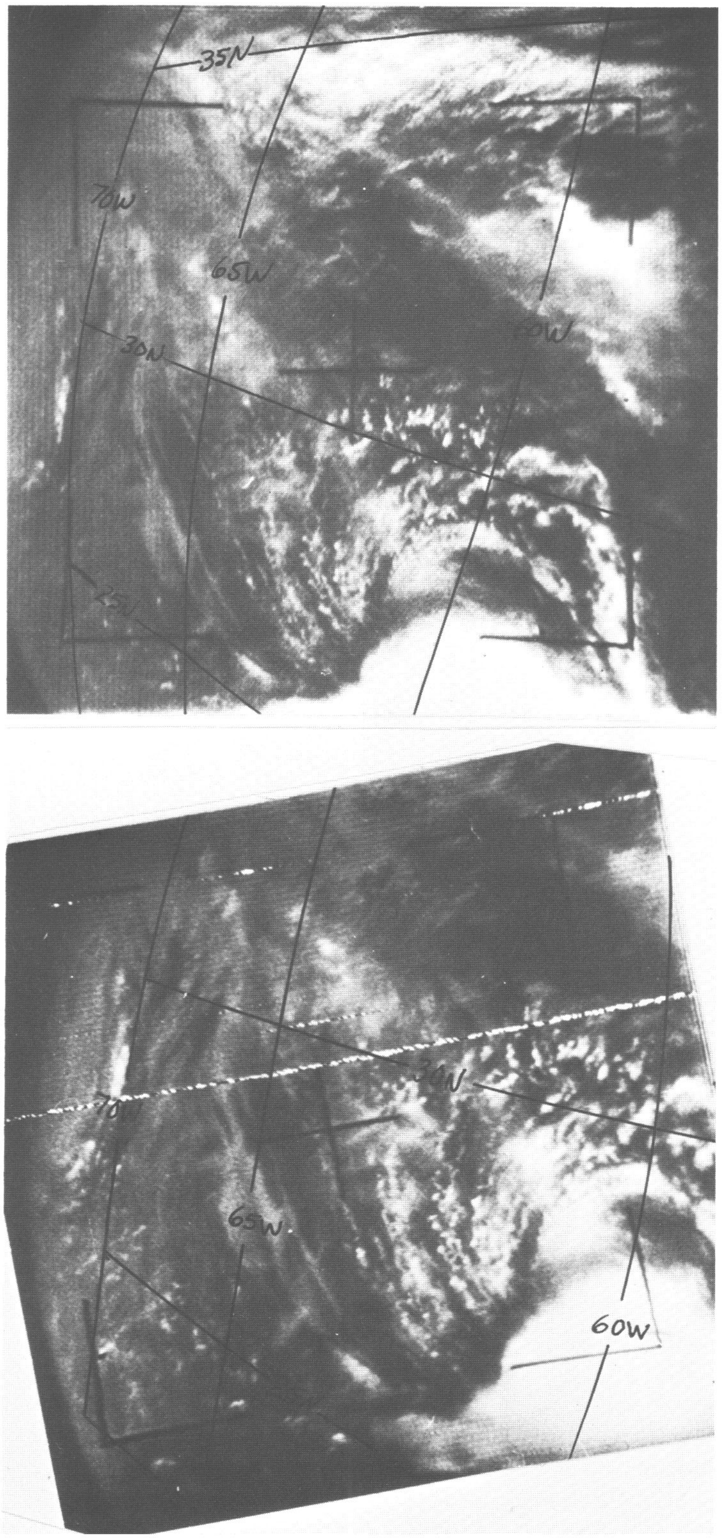

FIGURE 5.—Two TIROS VII views of hurricane Ethel centered near 27.8°N., 60.3°W. Hurricane Dora with maximum winds of approximately 100 kt. is visible in the upper left of each photo.

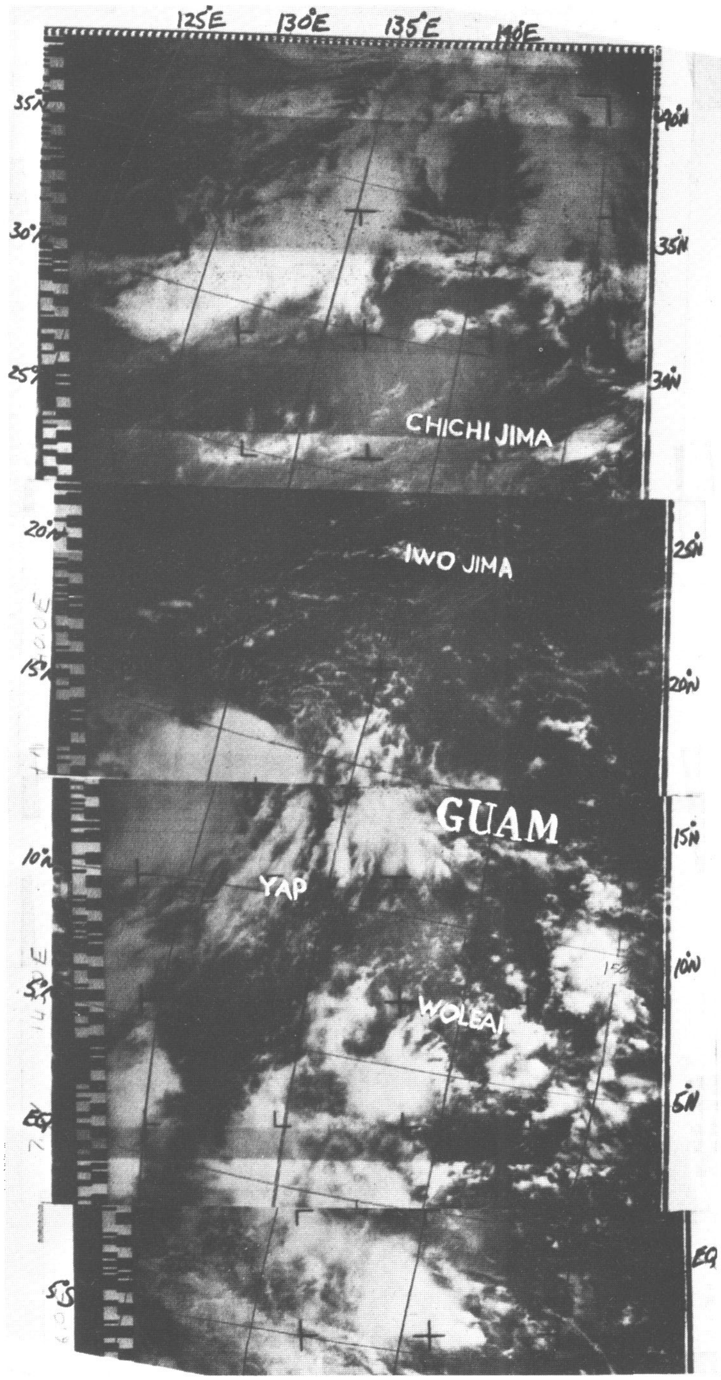

FIGURE 6.—A Nimbus II mosaic showing a formative stage of typhoon Billie on July 3, 1967, at 0213 GMT. The center of circulation is located near 16°N., 137.5°E.

of the storm on this day at 0213 GMT. A weak center of circulation can be detected north of major overcast cloudiness near 16°N., 137.5°E. An independent appraisal of pictures received at the Satellite Center in Suitland, Md., resulted in the following Miscellaneous Satellite Bulletin:

> "0459Z E17N 138 E Stage B, Dia X, Bands X. Loosely organized disturbance with most heavy cloudiness in Southwest quadrant."

Maximum surface wind speed observed from our aircraft was 30 kt. just southeast of the center. This is in good agreement with the estimate deduced from the satellite pictures indicating a Stage B or possibly Stage C tropical

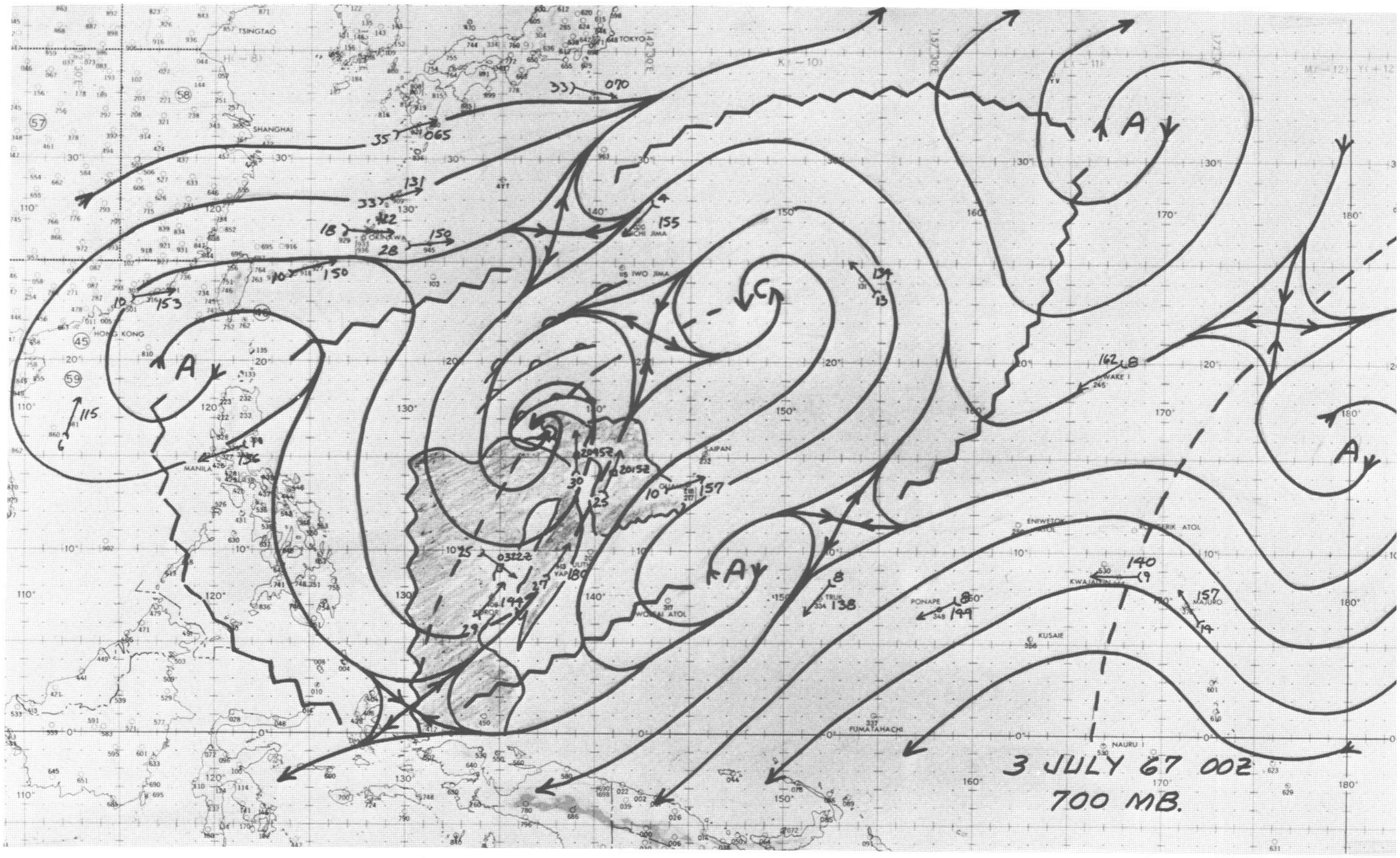

FIGURE 7.—The 700-mb. streamline analysis for July 3, 1967, at 0000 GMT. The Nimbus II observed cloudy area of figure 6 is superimposed on this analysis.

depression. Cloud lines that formed the center were stratocumulus with tops at about 3,000 to 4,000 ft. It was clear above. Figure 7 shows the 700-mb. analysis with some of the reconnaissance reports plotted showing wind speeds at this level. The aircraft descended to 1,500 ft. after the observation at 2045 GMT, July 2, to more closely pinpoint the exact center. Notable in this analysis is the major trough axis within which the circulation of Billie was embedded and the encirclement of this trough axis by ridge lines on the periphery. No temperature rise was noted at 1,500 ft. as the aircraft penetrated the center. Minimum sea level pressure determined through D-value measurements was found to be 997.6 mb. at the time of the penetration (July 3, 0322 GMT). Sparse upper level reports indicated that northeasterly flow existed over the storm area at the 200-mb. level. Northerly flow aloft would also have been deduced from cirrus streaks apparent in the satellite photos and from the sharp edge of cumulonimbus cloudiness south of the storm center with overcast conditions extending southward from this edge.

On July 4 and 5 the author again flew into the storm and fixed its position at 17.5°N., 128.0°E. (July 4, 2120 GMT) and approximately 6 hr. later at 17.9°N., 127.9°E. (July 5, 0330 GMT). Figure 8 shows the ESSA 2 picture on July 4 at 2320 GMT and in figure 9, Nimbus II pictures depict the storm area (July 5, 0302 GMT). Both figures indicate that the apparent center of the storm was still outside the main overcast cloudy area and that the storm was therefore still in a formative Stage C category, implying maximum wind speeds of about 30 kt.[1]

In comparison to the previous view (fig. 6) cloud streaks delineating the center are more obvious and for this reason it appears logical that the storm had intensified to some extent. However, the author was unprepared for the 70- to 80-kt. surface winds abruptly encountered at a distance of less than 100 mi. from the storm's center. Such typhoon force winds are normally encountered only after having penetrated several spiral bands and numerous rainshowers. In this instance at 10,000 ft. the sun was shining cheerfully and only the familiar raging seas with huge patches of boiling green below gave any indication that the eye of a typhoon was being approached. Scattered to broken lines of flattened cumulus and stratocumulus swirled in obvious curved alignment and it was no problem at all to look ahead about 50 mi. and see the eye of the storm defined by low cloud bands. Figure 10 is a picture

[1] An independent evaluation of pictures received at the Satellite Center, Suitland, Md., prompted the following bulletin: "04/0537Z E16N 131 E Stage B, Dia X bands X. Large area heavy clouds all south of center extending from about 137 E to near 120 E and to near 5 N. ESSA 5 949/947."

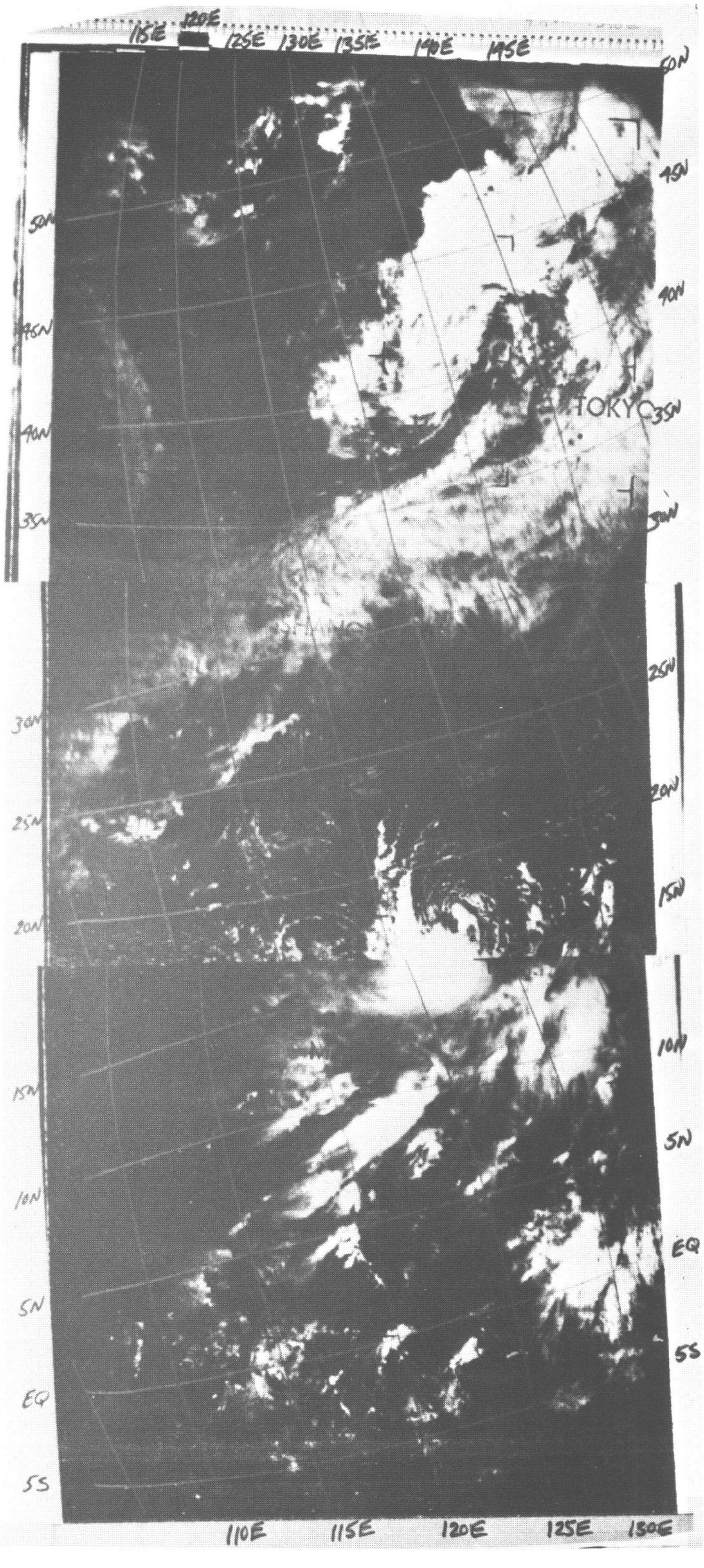

FIGURE 8.—An ESSA 2 mosaic showing typhoon Billie on July 4, 1967, at 2320 GMT.

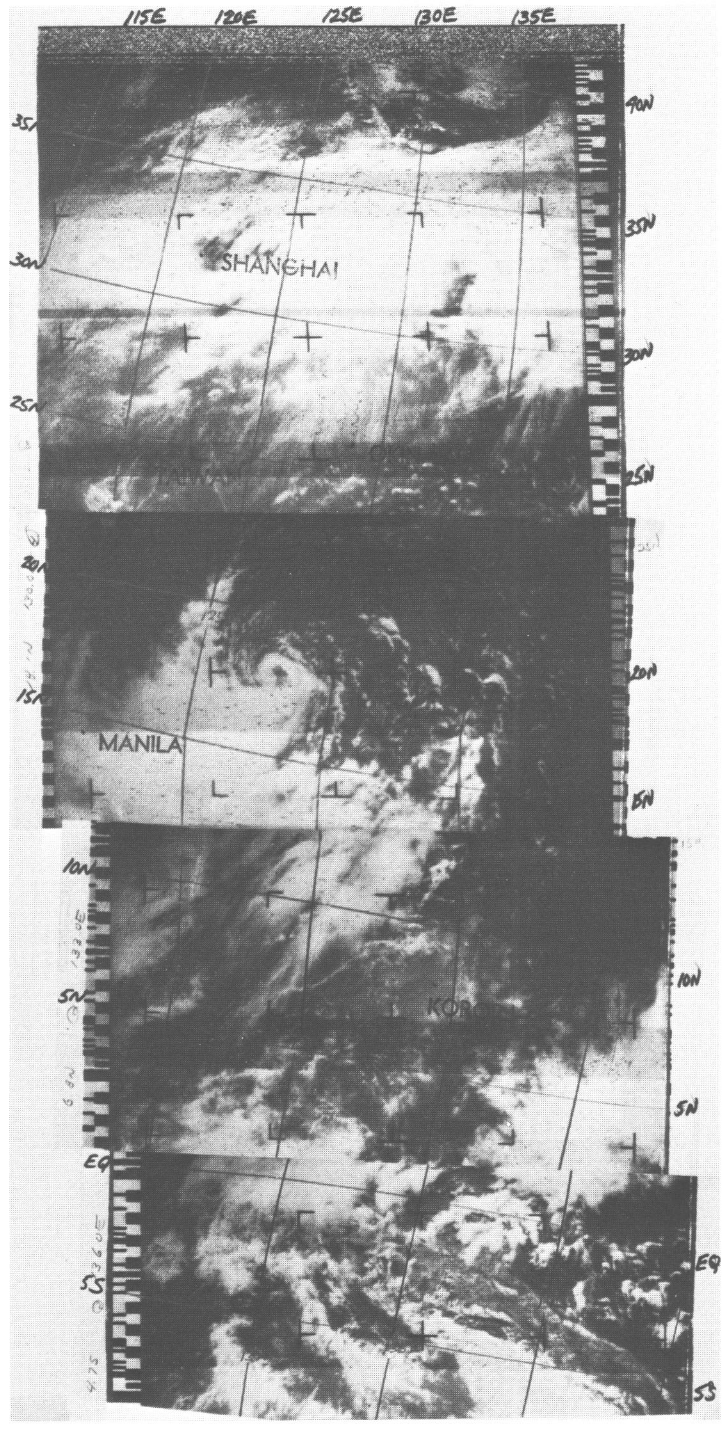

FIGURE 9.—A Nimbus II mosaic showing typhoon Billie on July 5, 1967, at 0302 GMT.

taken by the author of the eye of typhoon Billie at approximately 0330 GMT on July 5. This was less than 30 min. after the Nimbus picture of figure 9. The picture was taken from 10,000 ft. approximately 30 mi. south of the storm center looking toward the north. Cloudiness at the top of the picture is in the immediate vicinity of the aircraft.

From the combined information the author deduces that the eye of the storm in the Nimbus picture was located in the cloudy "hook" near 17.7°N. and 127.7°E. just west of the more open crescent-shaped slot which might easily be confused for the eye, lacking other evidence. The Nimbus APT TV picture lacks the power

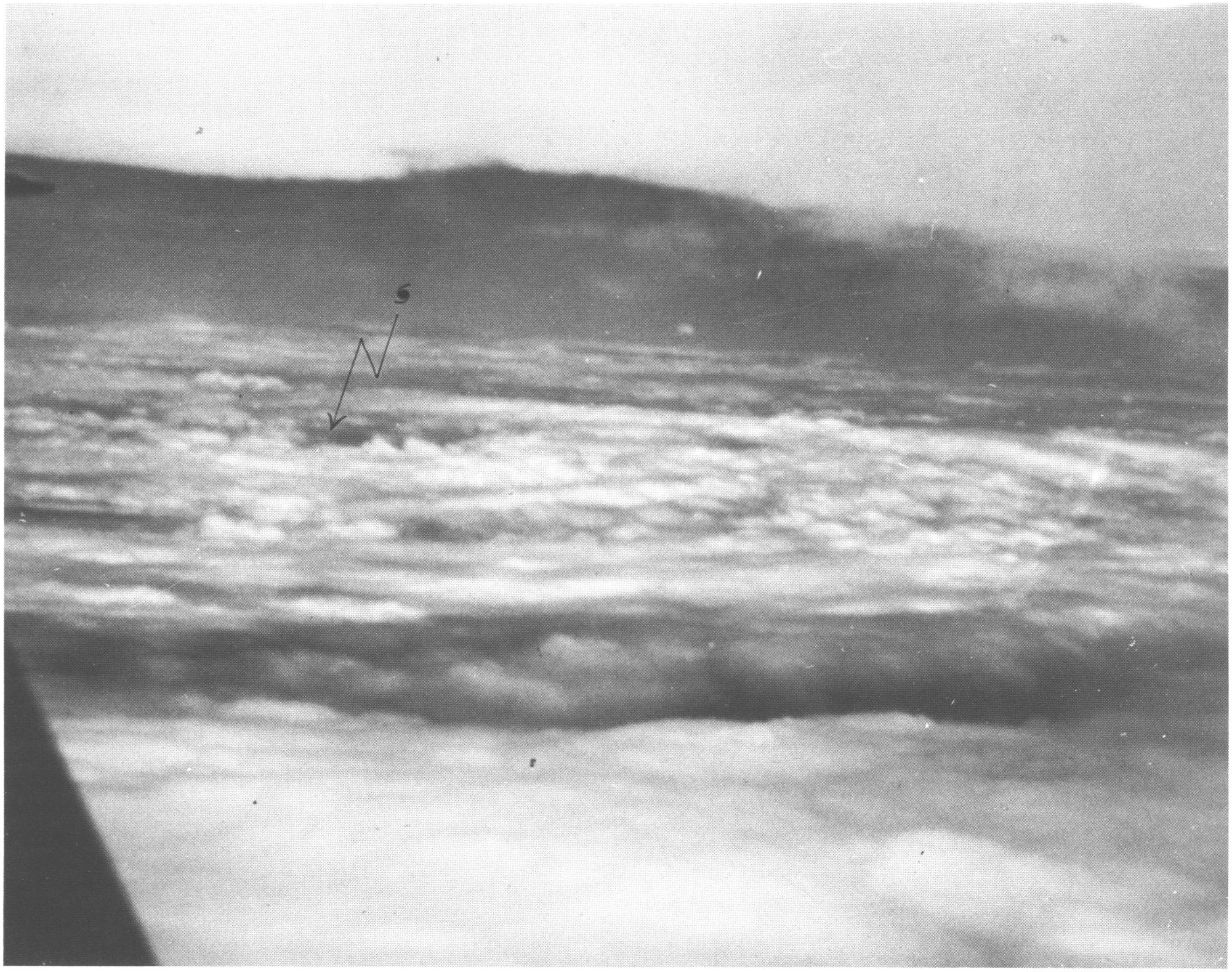

FIGURE 10.—A picture of the eye of typhoon Billie taken by the author on July 5, 1967, at 0330 GMT. The aircraft was flying at an altitude of 10,200 ft. approximately 30 mi. south of the storm when the picture was taken.

of resolution necessary to define the exact center or the microscale cloud swirls so readily apparent in the hand-held 35-mm. picture taken from the aircraft. *It is an extremely important point to emphasize that the clouds forming the eye of typhoon Billie were all low clouds with tops at no more than 4,000 to 5,000 ft.* In no sense of the word did a wall cloud exist around the center of the storm. Major convective buildups lay at least 30 mi. south of the storm center. (The distinction between high cloudiness to the south and low cloudiness to the north can most clearly be seen in the ESSA 2 pictures of figure 8.) Yet the storm had a very definite warm core. (The term "warm core" or "mesoscale warm core" as used in this paper refers to the area in the immediate vicinity of the eye or center of circulation. It is to be distinguished from the broader use of the term which applies to the warming as a result of the release of latent and sensible heat in the larger scale convective areas surrounding the storm center.) On the first penetration on July 4 at 2120 GMT, temperatures at the 726-mb. level rose from values of 14.1°C. a few miles away from the eye to a value of 17.2°C. directly over the eye. Minimum sea level pressure was determined through dropsonde into the eye to be 985 mb. On the second penetration at 700 mb. on July 5 at 0330 GMT, temperatures rose from values of 13.5°C. a few miles outside of the eye to a value of 18.5°C. directly over the eye. Minimum sea level pressure at this time was computed to be 982 mb. The exact center of the circulation, as can be seen in figure 10, was clear of clouds.

All of these observations are of extreme interest and will be discussed in detail in the section to follow. The synoptic analyses with superimposed cloud patterns derived from the satellite pictures are also of interest.

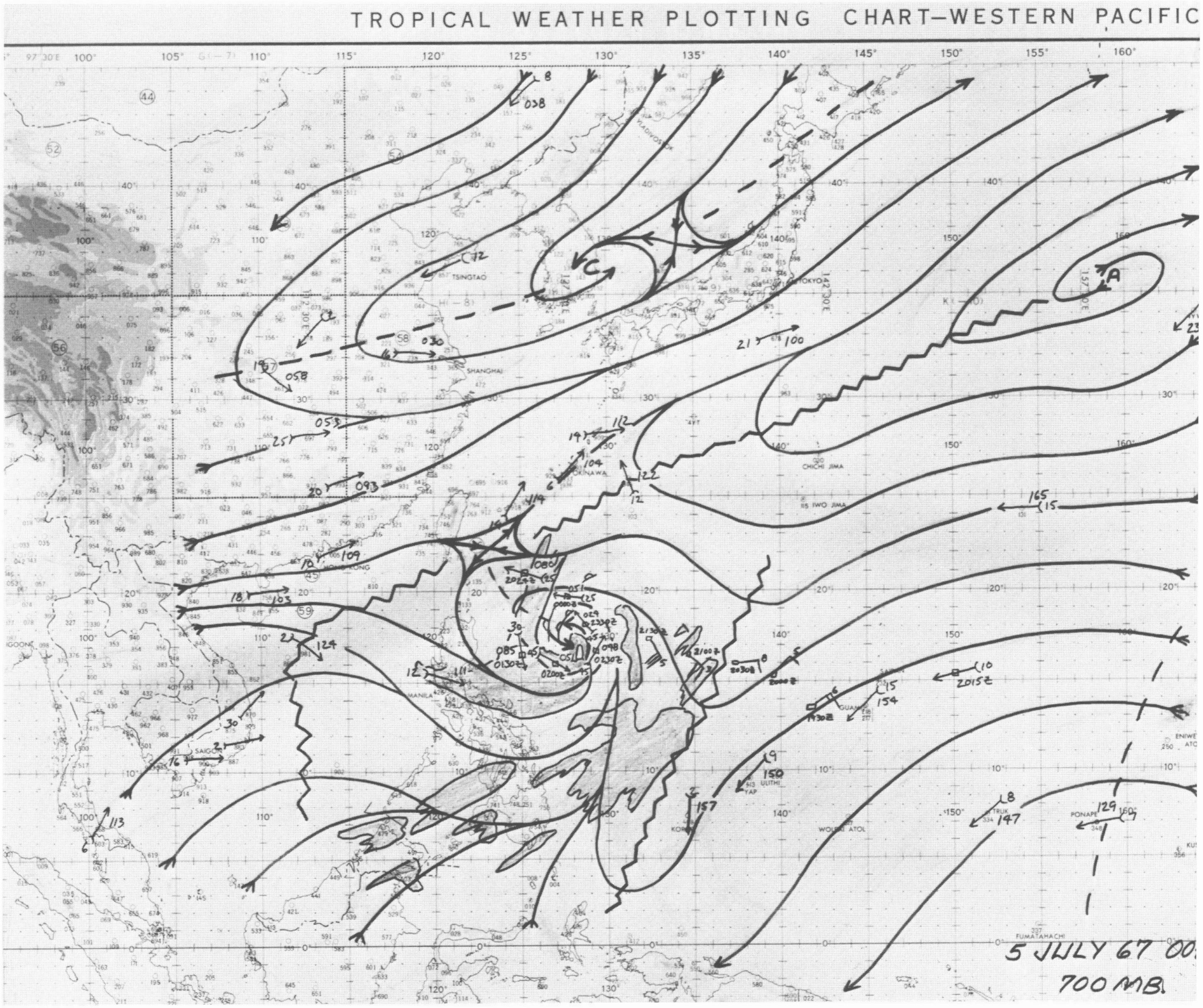

FIGURE 11.—A 700-mb. streamline analysis for July 5, 1967, at 0000 GMT. The ESSA 2 observed cloudiness of figure 8 is superimposed on this analysis.

Figure 11 shows the 700-mb. analysis on July 5 at 0000 GMT. A sharp ridge is still apparent around much of the periphery of the storm. Cloudiness extending south and southwest of the storm coincides with a convergence asymptote. The 200-mb. analysis (fig. 12) shows that strong upper level northeasterly flow still existed over the storm area. This type of flow prevented upper cloudiness formed by convection south of the storm's center from flowing northward over the eye.

4. SUGGESTED CONCLUSIONS

The fact that storms such as Billie can generate pressures low enough to produce winds of typhoon velocity in the absence of a wall cloud raises some questions concerning our understanding of "what goes on inside the eye?" Malkus [4] drew attention to the importance of the wall cloud as providing the ideal environment for air parcels to rise from surface layers releasing latent heat undiluted by entrainment of cooler, drier air of the outside environment. Warming at upper levels in the area of the eye established through this mechanism was thought to be more importantly enhanced through descent and adiabatic heating of air within the eye. This air descending from near the 200-mb. level was considered to have consisted of a mixture of air, already warmed, at the top of the wall cloud with some cooler, undisturbed, upper level tropospheric air. Initial cause for descent was unspecified but once established Malkus suggested that "the air descending in the eye probably is thrown out again into the rain band at low levels by excess centrifugal force, permitting more air to be incorporated and begin descending aloft." This commonly held view has been used to account for the low pressures and high

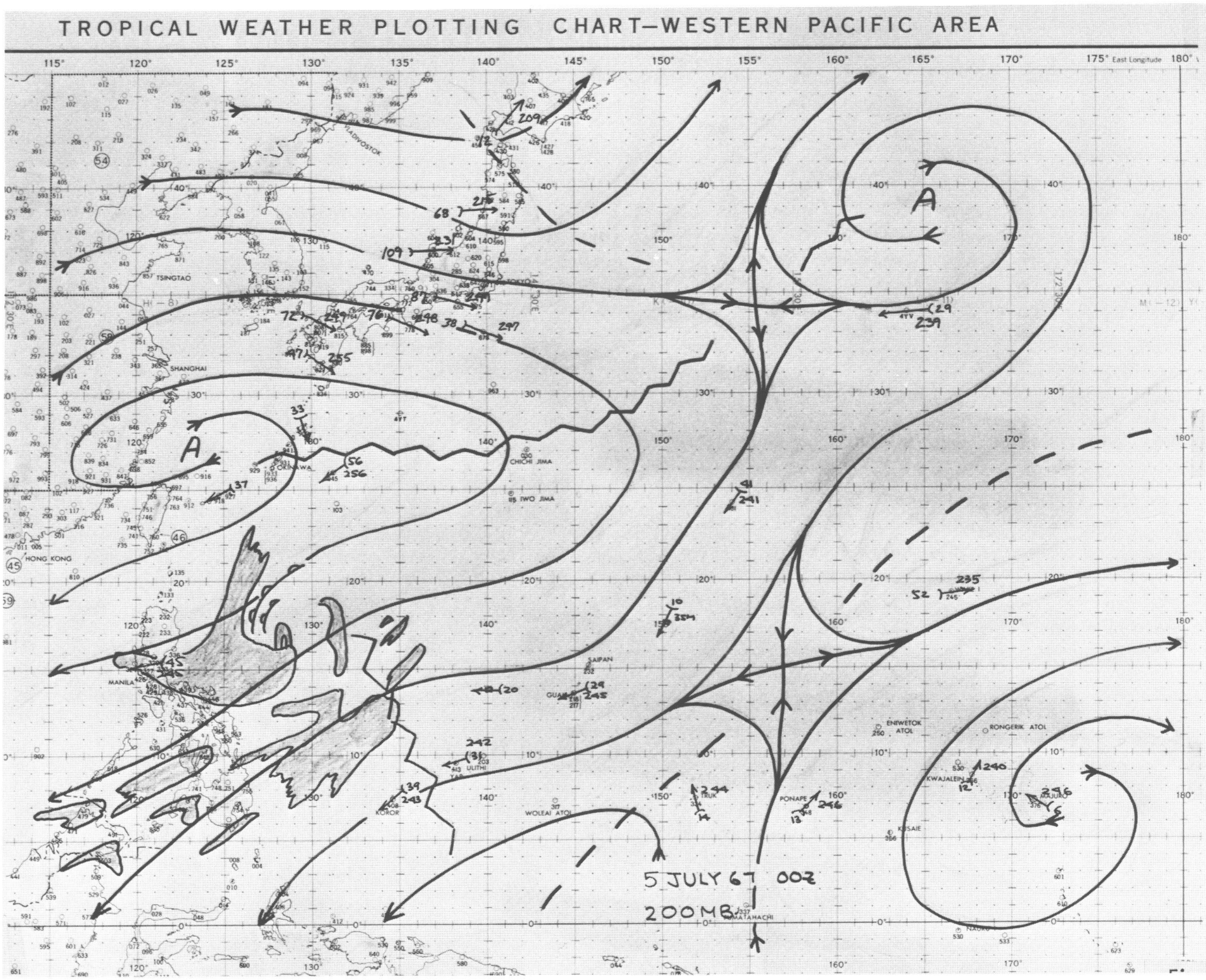

FIGURE 12.—A 200-mb. streamline analysis for July 5, 1967, at 0000 GMT. The ESSA 2 observed cloudiness of figure 8 is superimposed on this analysis.

wind speeds observed in hurricanes and typhoons. It cannot be called upon, however, to explain the unusual configuration exemplified by typhoon Billie.

The outstanding observation noted was that *Billie had a distinct mesoscale warm core despite the absence of a wall cloud* or any cloud for that matter above 5,000 ft. surrounding the eye. It was a quite remarkable experience to fly over the eye of this storm in absolutely clear conditions and watch the free air temperature gauge slowly but steadily rise as the exact center of the storm was approached and then drop off again on the other side in the space of only a few miles. The inescapable conclusion is that subsidence was occurring in a narrow, cloudless column over the eye resulting in the temperature increase observed. A comparison of soundings made from the aircraft shows that the eye sounding was much warmer than nearby environmental soundings and that this warming extended down to the 875-mb. level. This lower level also very closely approximated the height of the stratocumulus clouds observed in the area of the eye. Dropsonde information from the surface to 500 mb. obtained approximately 80 n.mi. southeast of the eye may be used to determine the approximate level from which air would have had to descend to account for the temperature increases noted in the eye sounding. If dry adiabatic descent is assumed (and this seems reasonable since the skies above 5,000 ft. were clear in the immediate vicinity of the eye), then initial descent must have commenced from somewhere near the 580-mb. level.

Data obtained were not adequate to permit investigations that might have offered a complete explanation for the intensification of Billie from July 3 (fig. 6) to the time it achieved typhoon intensity (fig. 8 and 9). It is apparent, however, that reasons for the intensification are intimately associated with the commencement or accentuation of subsidence in the narrow column above the eye. Warming achieved through this effect is the most reasonable mechanism to account for the rapid decrease in pressure (from 997.6 to 982 mb.) and increase in wind speeds (from 30 to approximately 80 kt.) noted during this period. If Billie was cold core in the area of the eye on July 3 (and this has not been definitely established) then intensification coincided with the change from a cold-core to a mesoscale warm-core system. The term mesoscale is used because on a larger synoptic scale no appreciable change could be detected in upper level analyses or in the general structure and appearance of the storm as observed from satellite. Compare closely figure 6, which shows Billie in its weakest state on July 3, to the picture of Billie with winds of typhoon force 48 hr. later (fig. 9). The pictures are amazingly similar. The only notable difference in the two pictures is that the original weak lines of convection that defined the circulation center in figure 6 have further developed, generated more cloudiness, and thereby have become more obvious in figure 9. According to the above observations it follows that the *transformation of Billie from a weak depression to a storm with typhoon force winds occurred as a result of changes not in the synoptic but rather in the mesoscale.* The type of mesoscale change necessary to bring about this transformation had to be such as either to initiate or increase divergence near the 875-mb. level in the area of the eye or, alternately, to force subsidence into the eye from aloft near the 580-mb. level. The former argument appears most reasonable, but only a concerted research effort into a storm of this type at the right time can bring back the type of data necessary to resolve the issue.

One final point should be made concerning Billie and other similarly configured storms. Billie, in the "no wall cloud" configuration, had maximum surface winds limited to approximately 80 kt. In a survey of similar storms viewed by satellite over the past 7 yr. it appears that this figure is fairly common as an upper limit for storms of the "Billie" variety. Storms with wall clouds on the other hand are often appreciably more intense. Reasons for the differences are immediately suggested. The upper limit in a storm of the "Billie" variety is necessarily prescribed by the temperature of the undisturbed tropospheric air drawn (or forced) into the eye. Higher temperatures in the eye of storms with wall clouds must be attributable to forced warming of air already warmed as a result of the release of latent heat within the wall cloud. Hence pressures can drop to lower values with corresponding increases in maximum surface winds.

5. SUMMARY AND FURTHER DISCUSSION

It has been established that winds of typhoon strength can exist around the eye of a storm that has no wall cloud at all and is delineated only by cyclonically curved lines of stratocumulus with tops at 4,000 to 5,000 ft. These storms have an appearance similar to a heightened or more intense version of the Stage C Comma Configuration shown in figure 1. Reasons for the transformation have been shown to be associated with the development of subsiding motion within the eye, resulting in the creation of a mesoscale warm core. Because of failure to develop a wall cloud these storms appear to have maximum-sustained surface winds limited to approximately 80 kt. At the same time it is not suggested that such storms never do develop wall clouds. On the contrary, typhoon Kathy, shown in figure 4, was reported earlier to have had a wall cloud and Kathy regained a well-defined wall cloud on later days in its history. Winds were appreciably more intense during the periods when a wall cloud was reported.

It is interesting to consider how different a storm of this variety would appear in its manifestations as it passed certain island stations located in its path. Inhabitants would have none of the usual signs of an approaching typhoon. Winds of 15 to 20 kt. out of the northeast could change in a matter of minutes to full typhoon intensity. And all of the time the sun could be shining brightly through scattered to broken deck of stratocumulus with no higher clouds above. Complete passage of the storm could occur in only a few hours, and never a drop of rain fall during the entire passage!

There are many other ramifications to this study, but meaningful discussion will depend upon the availability of much more detailed reconnaissance information coincident with high quality satellite pictures of the right storm at the right time.

ACKNOWLEDGMENTS

The author is indebted to Major William D. Roper and Staff of the Joint Typhoon Warning Center, Guam, for invaluable assistance and support in gathering material for this study and to Dr. Herbert Riehl for a very helpful and encouraging discussion.

REFERENCES

1. R. W. Fett, "Some Characteristics of the Formative Stage of Typhoon Development: A Satellite Study," a paper presented at the National Conference on the Physics and Dynamics of Clouds, Chicago, Ill., March 24–26, 1964 (unpublished Weather Bureau manuscript).
2. R. W. Fett, "Life Cycle of Tropical Cyclone Judy as Revealed by ESSA 2 and Nimbus II," *Monthly Weather Review*, Vol. 94, No. 10, Oct. 1966, pp. 605–610.
3. A. Timchalk, L. F. Hubert, S. Fritz, "Wind Speeds From TIROS Pictures of Storms in the Tropics," *Meteorological Satellite Laboratory Report* No. 33, U.S. Weather Bureau, Washington, D.C., Feb. 1965, 33 pp.
4. J. Malkus, "Tropical Weather Disturbances—Why So Few Become Hurricanes," *Weather*, Vol. 13, No. 3, Mar. 1958, pp. 75–89.

[*Received December 7, 1967; revised May 6, 1968*]